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PROPOSAL FOR A

MODULATED-LIGHT FILM VIEWING SYSTEM

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[redacted]

17 April 1964

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218-52A (5-63)
REF: ENGINEERING PROCEDURE S-017

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SECTION I - INTRODUCTION

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This proposal is submitted by [redacted] to perform a study of a Modulated-Light Film Viewing System. The proposed Phase One program is planned for completion within six (6) months from contract award. It is anticipated that a laboratory breadboard will be fabricated to demonstrate the feasibility of the chosen approach. The essential design features of a prototype model will be detailed sufficiently to initiate the subsequent design and fabrication of an operational prototype during a Phase Two program. The study program has been divided into four principle tasks, namely: (1) a review of applicable concepts, (2) implementation studies, (3) fabrication of a breadboard device, and (4) laboratory testing and evaluation.

The recommended design approach will be greatly dependent upon practical solutions to the problem of measuring the film image characteristics (density and spatial frequency) and providing a flicker free light modulation technique to adjust the illumination system of the light table.

Although various concepts will be detailed during the first month of the study, it is expected that the recommended approach will utilize a CRT modulation technique.

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The Phase Two program will be initiated only after successful demonstration of feasibility and approval by the customer. The Phase Two program will consist of the production of an operational prototype and a detail description of the equipment including maintenance and operating instructions.

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SECTION II - TECHNICAL DISCUSSION

1. GENERAL

The subject development objective of this program is to prove the feasibility, develop, and evaluate a Modulated-Light Film Viewing System. This system is to be used for direct viewing and high magnification viewing through a microscope. The brightness of the backlight must be modulated as a function of the transmissivity of the film and the spatial frequency so that the backlight intensity increases with a decrease in transmissivity and an increase in spatial frequency.

The detailed design of the light table will be dictated to a great extent by the light-modulation technique. Although there may be some problems in the detailed design such as auxiliary illumination, film handling mechanism, etc.; [redacted] feels that the major problems are those concerned with the detection of film image characteristics and modulation techniques. [redacted] further feels that the mechanical design problems can be solved by good engineering judgement and therefore will not be discussed in this proposal. Therefore, the technical discussion that follows will treat only the problems associated with detection of film characteristics and light modulation. 25X1A 25X1A

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2. REVIEW OF MODULATION TECHNIQUES

There are several possible methods of modulating the backlight of a film as a function of film transmissivity that have been used in printers and enlargers. Examples of these include an enlarger utilizing a modulated CRT as a light source and a contact printer that utilizes phosphor quenching. Other techniques include the addition of a second film that has been spatially modulated as a function of the transmissivity of the original image. Photochromic and phototropic materials can be exposed to give a modulated transmissivity which, if registered with the original image and the combination backlighted, can yield the desired modulated light.

It is conceivable that light sensitive material could be modulated according to spatial frequency content utilizing physical optics; however, none of these techniques appear amenable to a light table implementation.

An extension of the CRT modulation principle, with a high resolution, short persistence CRT, could be utilized to detect high spatial frequency information and provide light modulation as a function of both transmissivity and high spatial frequency information. It is also possible to increase the dynamic range of the modulation utilizing phosphor quenching in combina-

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tion with a scanning CRT backlight.

Another modulation technique worthy of investigation is dark field illumination utilizing oblique lighting. With this type of lighting, the high spatial frequency areas diffract more light into the viewers eye thus providing automatic dodging. This technique, used with the CRT modulation principle, which modulates the light according to transmissivity, could provide the necessary modulation for the subject light table.

These techniques are described below.

3. CRT MODULATION TECHNIQUE

a. General

The most promising approach for light modulation consists of modulating a CRT used as the backlight. The characteristics of the film are determined using a flying spot scanner and associated logic circuit operating on the resultant video, which modulates the intensity of the CRT. The CRT used as the flying spot scanner can also function as the primary light source or an auxiliary CRT can be added for this purpose.

b. Film Sensing Techniques

The film characteristics such as transmissivity and spatial

[redacted]

frequency content can be detected by flying spot scanner techniques. This can be done conventionally by imaging the CRT raster on the film from within the light table and detecting the light modulation on a photomultiplier mounted above the film. This, however, is quite objectionable since the photomultiplier would interfere with the operator.

An alternate approach utilizes a partial reflector located above the film so that a portion of the light transmitted through the film is reflected back to the photomultiplier. The light path is shown in Figure 1. This scheme has been evaluated in the laboratory using a partially silvered mirror and showed very good results. This reflector could have high spectral selectivity such as an interference filter and could be located near the edge of the visible spectrum. A highly selective filter that passes only the light reflected by the reflector can be located immediately in front of the photomultiplier to eliminate noise due to ambient light. An advantage of this approach is that all sensing equipment is located within the light table. A disadvantage is that it requires a glass over the film. For highest resolution of the detection system, the partial reflecting glass should be flat against the film. It can be elevated somewhat for viewing moving film but the resolution of the high spatial

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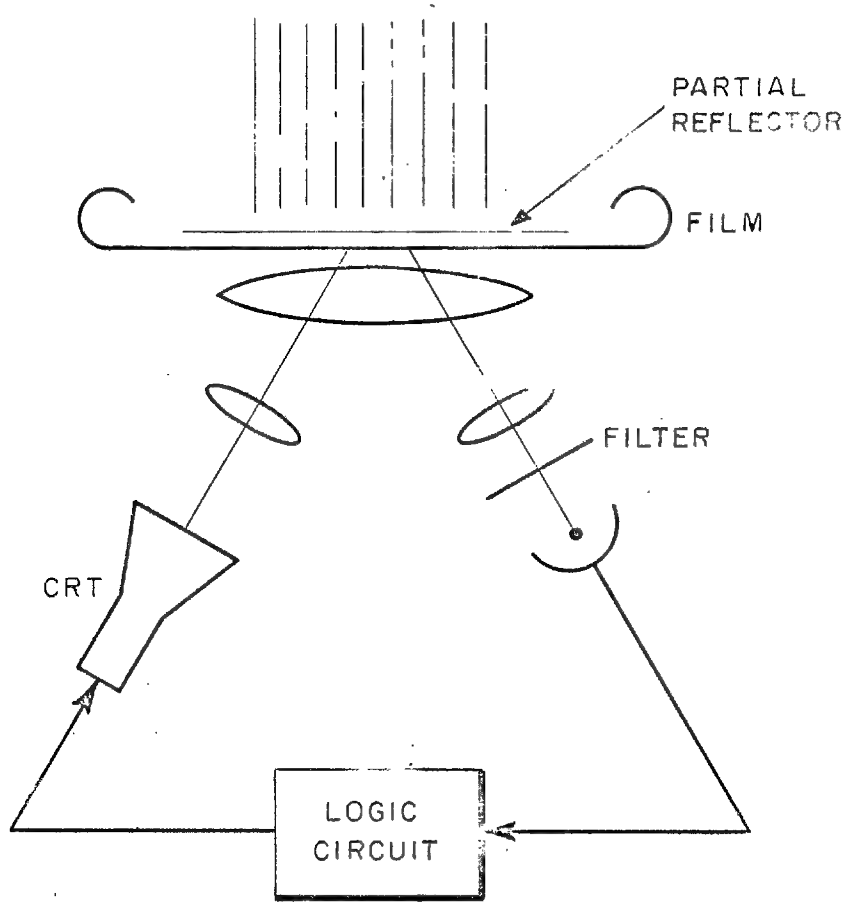

Figure 1. Film Sensing Technique

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frequency detection system will be reduced. The glass should not affect the transmissivity detection system and this type of dodging could be obtained even while the film is moving.

Another approach consists of utilizing the film base material (assuming emulsion side down) to reflect a portion of the light back to the photomultiplier. This would eliminate a glass on top of the film. The primary problem with this approach is that the film must be held very flat if it is to be used to reflect light. Still another approach is to utilize the relationship between transmissivity and reflectivity of the emulsion itself. This technique also requires flat film and eliminates the requirement for glass on top of the film.

c. <u>Scanner Considerations</u>

The CRT should serve as a backlight for the film and a flying spot scanner for the generation of video for the modulation circuitry. These are opposing requirements. To meet the backlight requirements, the phosphor should have relatively long persistence to provide high average brightness. In addition, the interline noise (raster line noise) must be minimum and the field rate should be above the critical flicker frequency. A small spot size is not required

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since its purpose is to simply provide a controlled backlight over various areas of the film.

In the generation of video adequate to sense high spatial frequencies, the spot size must be very small and the phosphor persistence short to obtain high-resolution video. If the spot size is small, the number of raster lines must be increased to cover the complete format. This results in sweep rates that are prohibitively high.

To illustrate the above requirements, let us consider them separately. Backlighting and modulating according to film transmissivity can be accomplished with a single, high intensity CRT. Ideally, the backlight should be a white P-4 type phosphor. The blue component of the P-4-Sulfide type phosphor has a decay time (to 10 percent amplitude) of approximately 20 microseconds. This phosphor can be excited to approximately 2000 foot-lamberts with a beam current of 300 microamperes. A [redacted] tube, [redacted] should meet these requirements. Theoretical and experimental investigations have shown that the effective bandwidth of a phosphor is:

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$$\overline{BW} = \frac{.3}{\text{decay time}}$$

A 20 μ sec decay time give an effective bandwidth of 15 KC.

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With a reasonable amount of compensation in the video amplifier, this upper corner can be increased to about 40 KC. In calculating resolution, the spread function of each aperture (spot size, bandwidth, lens, etc.) is assumed to be gaussian. In addition, the width of the spread function to the half amplitude points is defined as $W_{1/2}$. It has been shown* that:

$$W_{1/2} = \frac{.312D}{\overline{BW}\ \tau}$$

where

$\overline{BW}$ = 3 db upper corner of frequency response

D = distance across the sweep image (10" assumed)

τ = sweep time

The total number of resolvable elements across a sweep is then

$$N_H = \frac{D}{W_{1/2}} = \frac{\overline{BW}\ \tau}{.312}$$

Using a conventional TV sweep time, τ, of 53 μ sec, the number of resolvable elements with a 40 KC bandwidth is

$$N_H = \frac{(40)(53)(10^3)(10^{-6})}{.312} = 6.8$$

25X1A * [redacted] - Electronic Display Studies dated 2 January 1964.

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A trade can be made between horizontal and vertical resolution to make the number of resolvable elements equal in the horizontal and vertical directions.

The horizontal sweep time is a function of the number of vertical lines and the frame rate

$$\tau = \frac{1}{FN_V}$$

where

F = total frames per second

N_V = number of vertical lines

Equating the two, we have

$$N_V = \frac{1}{\tau F} = N_H = \frac{\overline{BW}\ \tau}{.312}$$

$$\tau = \left[\frac{.312}{F\ \overline{BW}}\right]^{1/2} = 510\ \mu\text{ sec for } \begin{array}{l} F = 30 \text{ cps} \\ \overline{BW} = 40 \text{ KC} \end{array}$$

and

$$N_V = N_H = 65$$

A resolution of 65 elements appears adequate in sampling the transmissivity of the film and controlling the backlight. It is, however, completely inadequate for detecting high spatial frequencies. In obtaining high resolution scanning,

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one limitation is the maximum number of resolvable elements across the face of a CRT. Regardless of size, the maximum number of resolvable elements ($W_{1/2}$) is about 6000. Assuming a ten-inch image of the sweep, then

$$W_{1/2} = \frac{10 \times 25 \text{[illegible]}}{6000} \text{[illegible]}$$

This can be related to detectability of spatial frequency by Figure 2 which shows the gaussian response to a square wave. For detecting a modulation signal, a level of 5 percent appears very reasonable. Then

$$\nu = 1.1 = \frac{\delta}{\lambda}$$

and since

$$\delta = \frac{W_{1/2}}{.7}$$

$$\lambda = \frac{W_{1/2}}{.77} = \frac{.042}{.77} = .0545 \text{ mm}$$

This means that scanning a resolution pattern of slightly over 18 lp/mm would yield a modulation of 5 percent. This, of course, assumes that the scanning system resolution is spot size limited only. This implies that the video amplifier and phosphor decay has a sufficiently high bandwidth. With proper video compensation, a P-16 phosphor has

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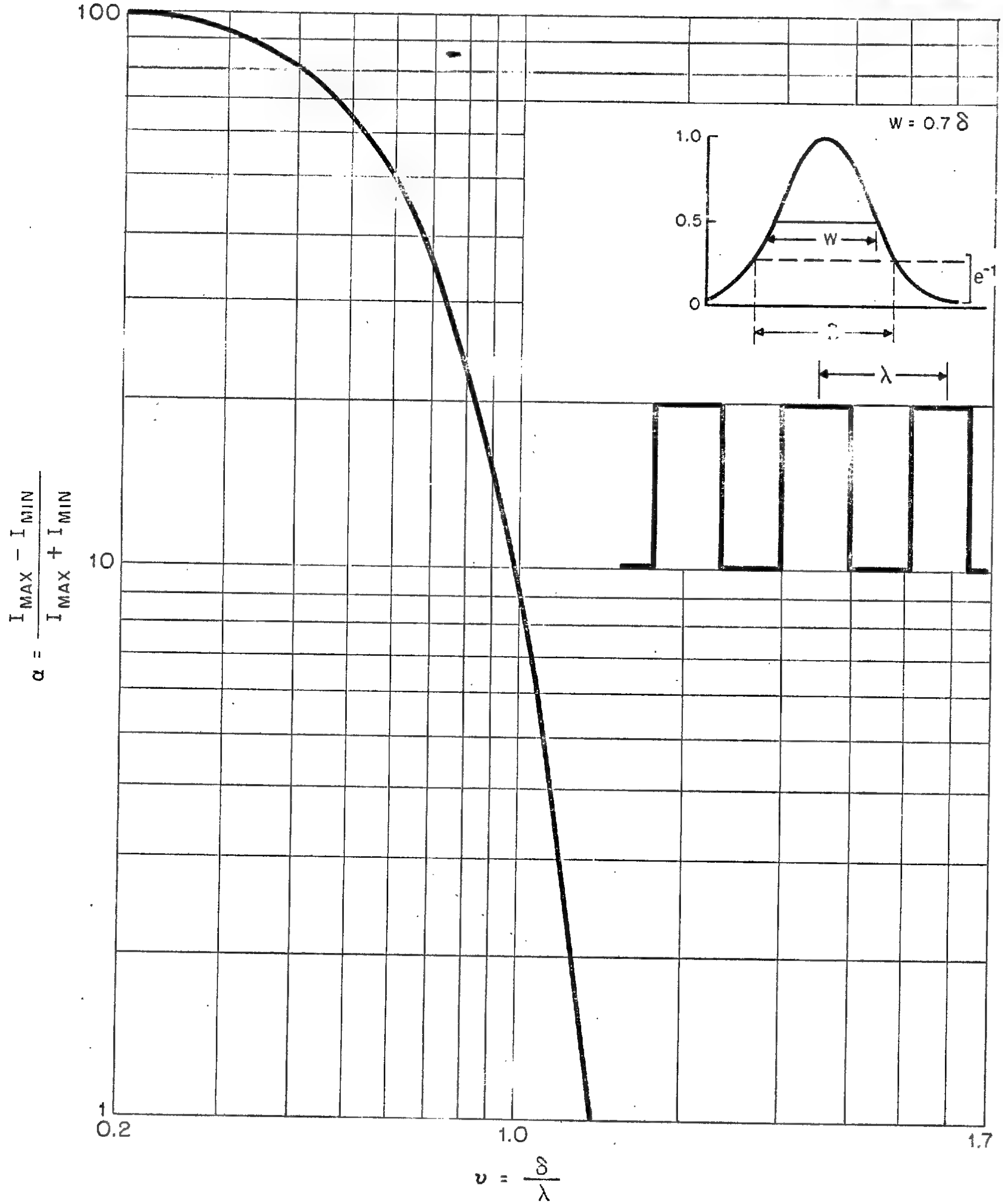

Figure 2. Square Wave Responses for Gaussian Aperture

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a bandwidth of 8 mc and video amplifiers with the necessary gain have been designed with bandwidths of about 20 mc. If we use the same sweep time as computed above for the P-4 phosphor CRT, the resultant width of the spread function is:

$$W_{1/2} = \frac{.312\ D}{BW\ \tau} \qquad \frac{(.312)(254)}{(8)(510)} = .0195 \text{ mm for the P-16 phosphor}$$

$$W_{1/2} = \frac{(.312)(254)}{(20)(510)} = .0078 \text{ mm for the video amplifier.}$$

This corresponds to a 5 percent modulation at 39 lp/mm and 99 lp/mm respectively. As can be seen, with a sweep time of 510 μ sec, the limiting aperture of the video circuit is the size of the spot on the CRT.

The above analysis indicates that a single CRT cannot provide adequate resolution for detecting high spatial frequencies and still provide backlighting and transmissivity dodging. A large spot size long persistence CRT can provide the latter; however, a high resolution short persistence CRT must be used for the high frequency detection. The transmissivity of the film should be detected with the large spot on the P-4 CRT since the transmissivity measured will

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be the average over the area being illuminated.

Figure 3 shows a possible configuration using two CRT's. As indicated above, the raster consists of about 65 lines. In order to eliminate objectionable raster lines, the spot size on the P-4 CRT should be at least $\frac{1}{65}$ the diameter of the tube. Using the same raster parameters for the P-16 CRT, the scene will be sampled 65 times in the vertical direction and all of the high frequency detection will be done horizontally. The two rasters can be rotated on alternate fields or frames so that high frequency detection can be accomplished in both directions. This still does not provide detection over the whole scene but only along the raster lines. It may be possible to dither the spot in order to increase the sampled area.

The two CRT's can be swept in synchronism. The two sweeps can be tailored somewhat so the two spots fall on the same area on the film. The registration problem is not too severe because of the large spot on the P-4 CRT.

Other techniques are available to increase the resolution of the spatial frequency system. As mentioned previously, the high spatial frequency detection system is spot size limited at about 18 lp/mm. This resolution can be increased

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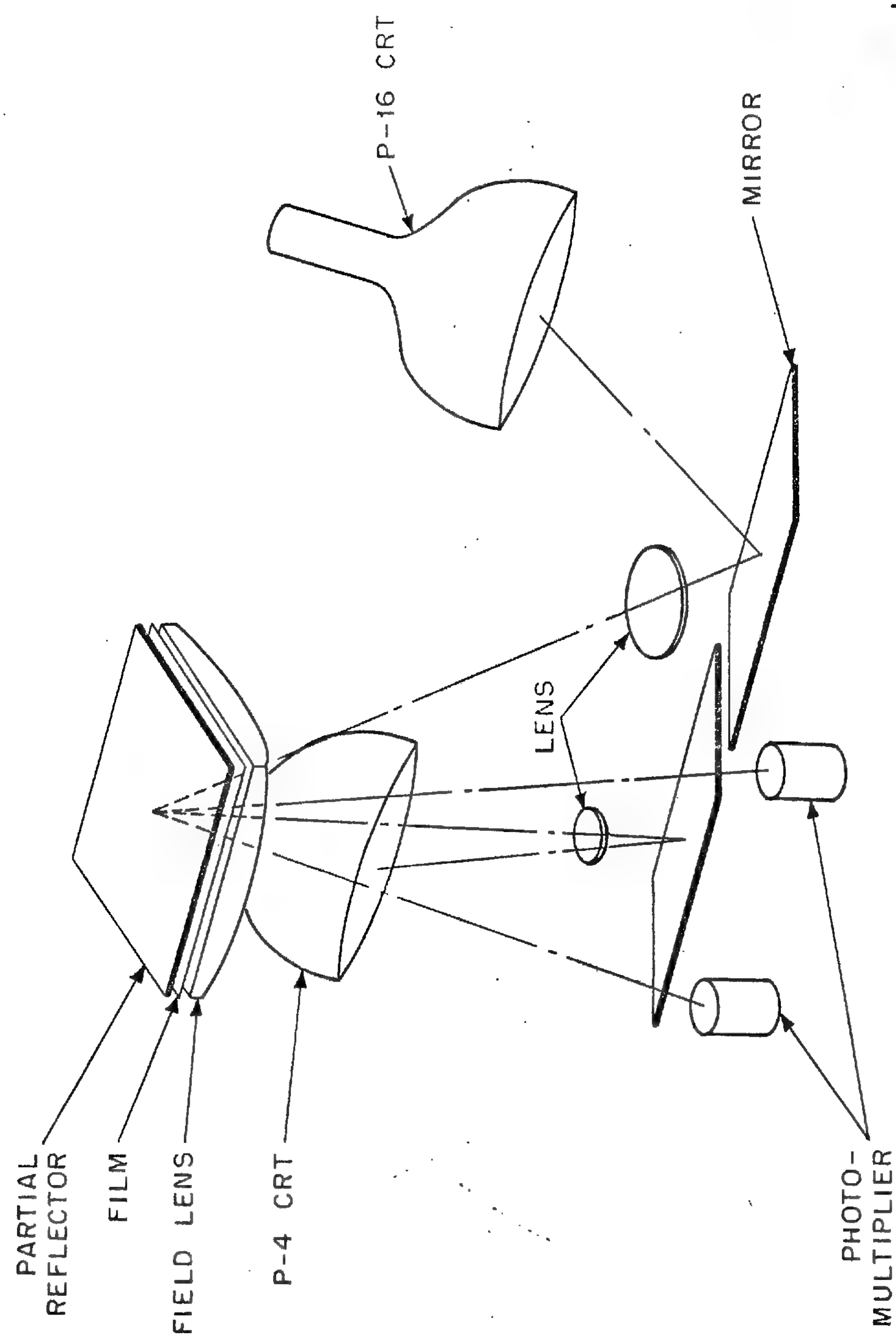

Figure 3. Modulation System Using Two CRT's

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by optically reducing the image of the spot on the film. This, however, results in a reduced coverage of the raster. In order to obtain full coverage the raster image must be translated over the format using a translating lens. If full coverage of the format must be maintained with the P-4 backlight then the two sweeps can no longer be in synchronism thus necessitating an intermediate storage device such as a scan conversion tube. With such an arrangement, the output of the logic circuit produces a backlight intensity value which is stored in the read-in portion of the scan converter. The read-in sweep would be kept in synchronism with the P-16 CRT sweep. This results in a charge pattern on the storage grid proportional to the intensity of the required backlight level. The read-out beam and the P-4 CRT beam are then swept in synchronism and the brightness is controlled by the read-out video. Scan conversion tubes with sufficient resolution for this application are presently available. This scheme increases the complexity of the system considerably and it is recommended as a Phase Two type development. The resolution of 18 lp/mm available with fixed optics and without the added complexity of the scan conversion tube and the scanning lens appears adequate for a prototype model. It is felt that areas of the image having very high spatial frequencies (50 lp/mm and up) also have sufficient energy at

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18 lp/mm for detection.

d. Logic Circuit Considerations

As shown in Figure 4, a portion of the spot's light proportional to the local photographic transmissivity of the picture is reflected into a phototube P followed by a voltage amplifier A. The input of the latter will be a voltage e_i proportional to the transmissivity $T(x,y)$ at the point x,y, namely:

$$e_i = k\,T(x,y)\ ,$$

where k is a constant gain.

Since a television mode of scan is assumed, with the raster lines running in the x-direction,

$$x = vt,$$

where v is the linear velocity of the spot. Hence

$$e_i = k\,T(vt,\ y)$$

Thus e_i becomes a function of time, and, as such, it is amenable to dynamic manipulation.

Some filtering of e_i may be necessary, in order to remove

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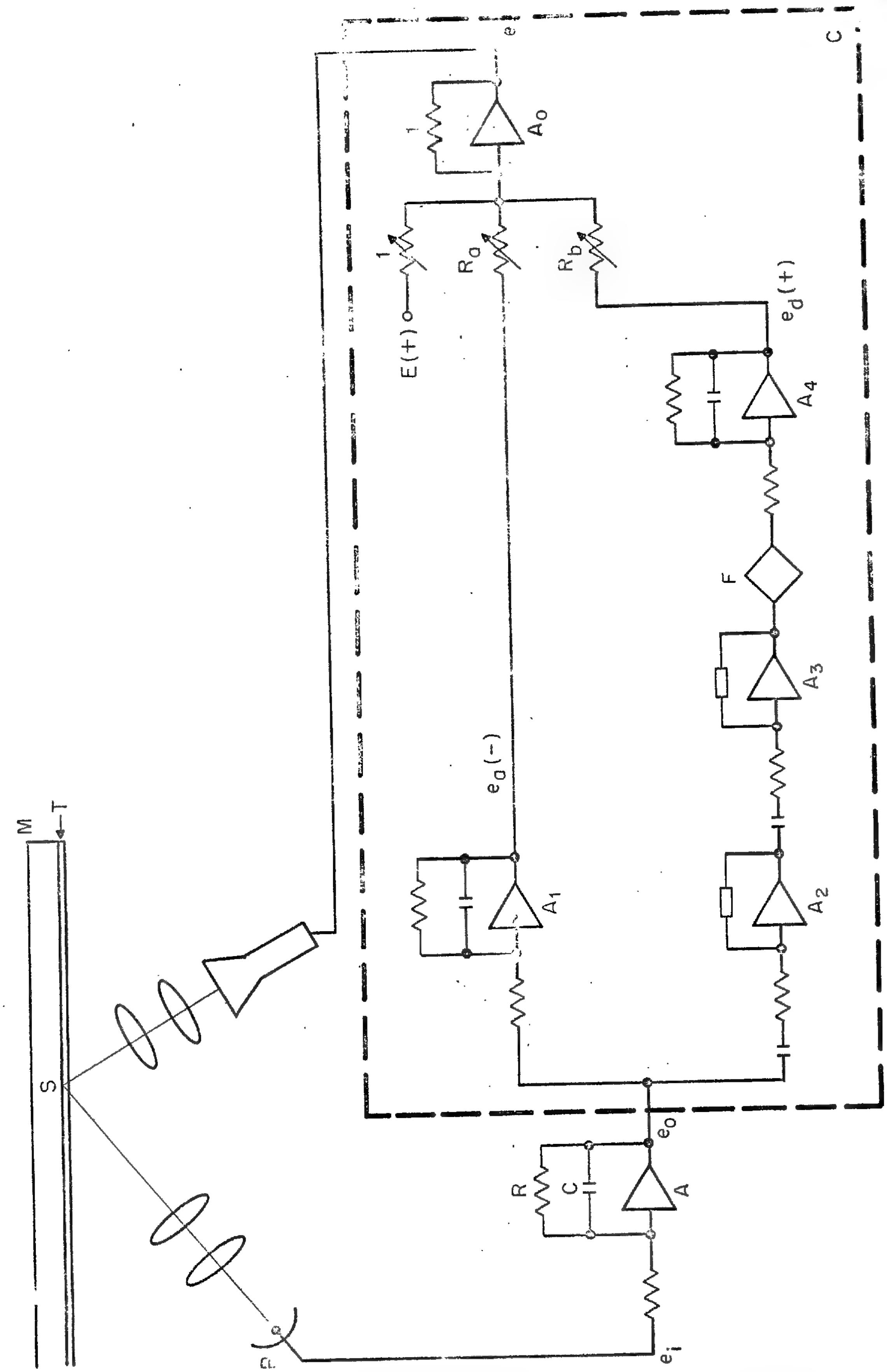

Figure 4. Modulation Logic Circuit

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emulsion and phosphor grain noise. This could be done easily in the amplifier A itself through an RC feedback branch, and it will result in an output e_o whose operational form will be

$$e_o(s) = \frac{e_i(s)}{\tau s+1} ,$$

τ being the appropriate time constant and s the Laplace operator.

The voltage $e_o(t)$ can be used to adjust the brightness of the flying spot provided that adequate criteria are set. Two such criteria suggested by the purpose of the proposed system are:

1. The average local brightness level must be kept constant over the picture.

2. The brightness of any picture area should be raised in proportion to the amount of detail present in the area.

The two criteria can be applied as follows. The signal e_o is sent to two parallel branches of the brightness control circuit C. In the upper branch, comprising amplifier A_1, a

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running average e_a of e_o is computed and compared with the reference voltage E in the output amplifier A_0. If e_a is low, the difference $E - e_a/R_a$, will cause the control voltage, e, to rise and increase the spot brightness since e is z-modulating the CRT. The reverse will happen if e_a is high. In the lower branch, a wide open differentiator, A_2, generates a rectangular wave in response to the fluctuations of e_o, which fluctuations are due to the presence of detail in the picture. The zero crossings of the rectangular wave are in turn obtained in the form of a pulse train by means of a second differentiator, A_3, followed by a fullwave rectifier, F. A running average, e_d, of this pulse train is computed by means of amplifier, A_4, and fed into the control amplifier, A_0, whose final output thus becomes

$$e = -\left[E - \frac{e_a}{R_a} + \frac{e_d}{R_d}\right]$$

Thus the more detail present the higher e_d is and therefore, the higher e becomes. Hence the CRT spot is made brighter. The gains $1/R_a$ and $1/R_d$ may be adjusted so that e_d outweighs e_a in either linear or non-linear fashion. For instance, a cross-coupling between the two branches may be established through which e_d may suppress e_a when e_d exceeds a certain threshold, etc.

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Because the approach outlined above depends on running averages, it is obvious that the control voltage $e(t)$ at time t depends on the signal $e_1(t - \Delta\tau)$ at a slightly earlier time $(t-\Delta\tau)$, where $\Delta\tau$ depends on the selected time constants of the running average circuits. This results in a slight lag depending on the value of $\Delta\tau$; however, it is felt that this lag is not serious due to the large spot size of the P-4 phosphor CRT.

e. Frame Rate Considerations

The frame rate of the CRT modulated light viewing system must be high enough to eliminate flicker. Figure 5 shows a plot of critical flicker frequency versus brightness for various persistence rates and viewing parameters. It can be seen that for a given brightness, the CFF decreases a ρ decreases. The persistence of the yellow portion of a P-4 phosphor results in a t/T of about 0.5 to 1. The range of values of ρ are applicable only to TV type viewing. In the light table application, ρ may be less than unity. No data is available below a ρ of 4 so the critical flicker frequency for nominal viewing distances and scene brightness must be determined experimentally. It is possible that the field rate necessary to eliminate flicker will be above 60 cps (frame rate of 30 cps).

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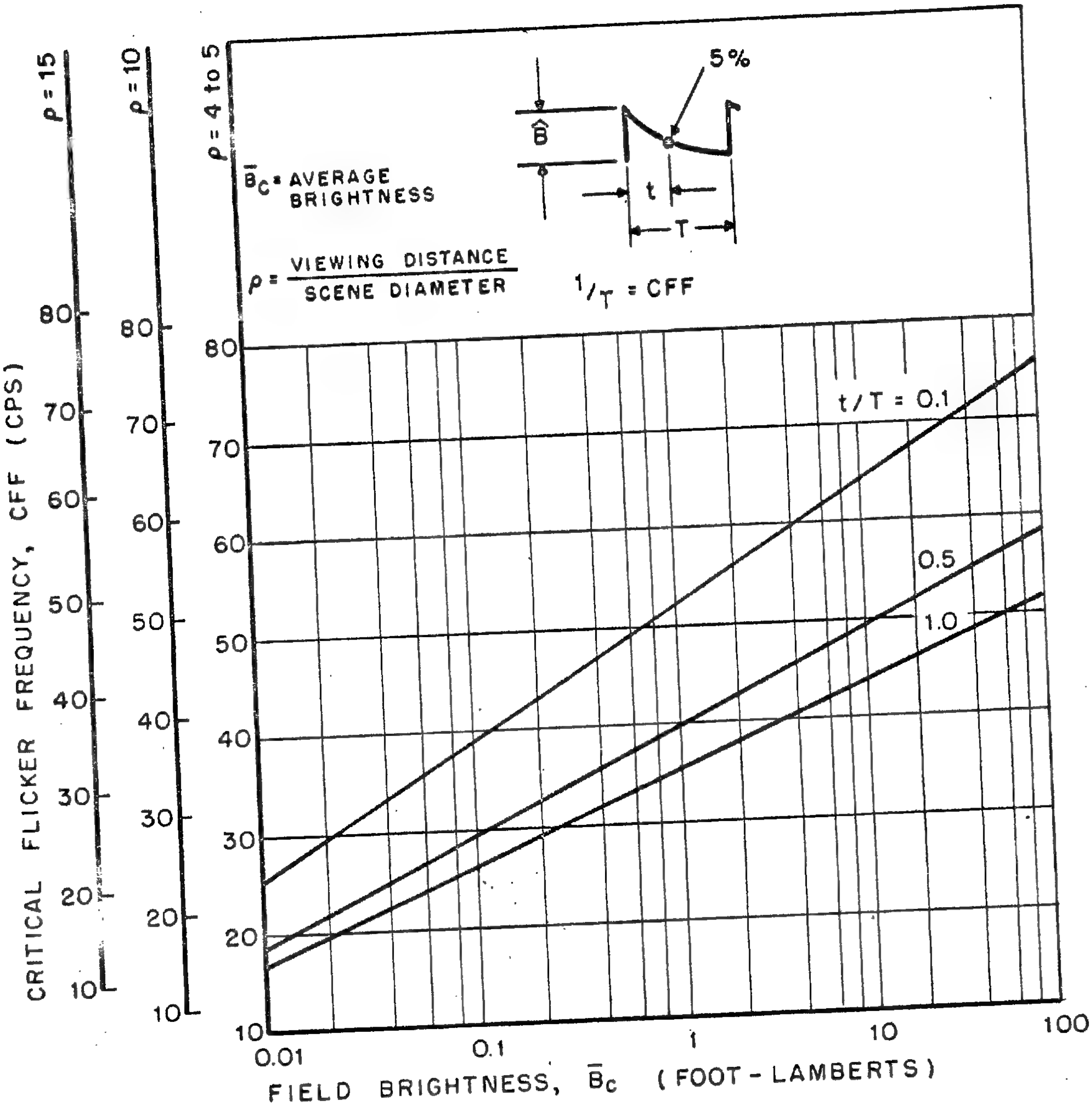

Figure 5. Critical Flicker Frequency Versus Field Brightness

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4. CRT MODULATION WITH PHOSPHOR QUENCHING

a. General

This section discusses the possibility of combining the CRT modulation technique described above with phosphor quenching in order to increase the range of modulation.

b. Phosphor Quenching

The dynamic range of a CRT is limited to about 15 to 20 db which may not be adequate to handle the dynamic range of the film. It is possible to choose a phosphor on the backlighting CRT that can be quenched. A P-28 phosphor, for instance, can be quenched with orange light. Figure 6 shows a configuration that utilizes phosphor quenching. The film is flooded with orange light which goes through the film and is reflected back and imaged on the phosphor using the same lens as is used for imaging the CRT raster on the film. With this technique, areas that have a high transmissivity will cause more quenching light to impinge on the phosphor thus reducing its brightness. It is felt that a dynamic range of at least 10 db can be obtained through quenching thus resulting in a total dynamic range of the combination of from 25 to 30 db.

One of the problems with this approach is obtaining a phosphor that is relatively white and can be quenched by

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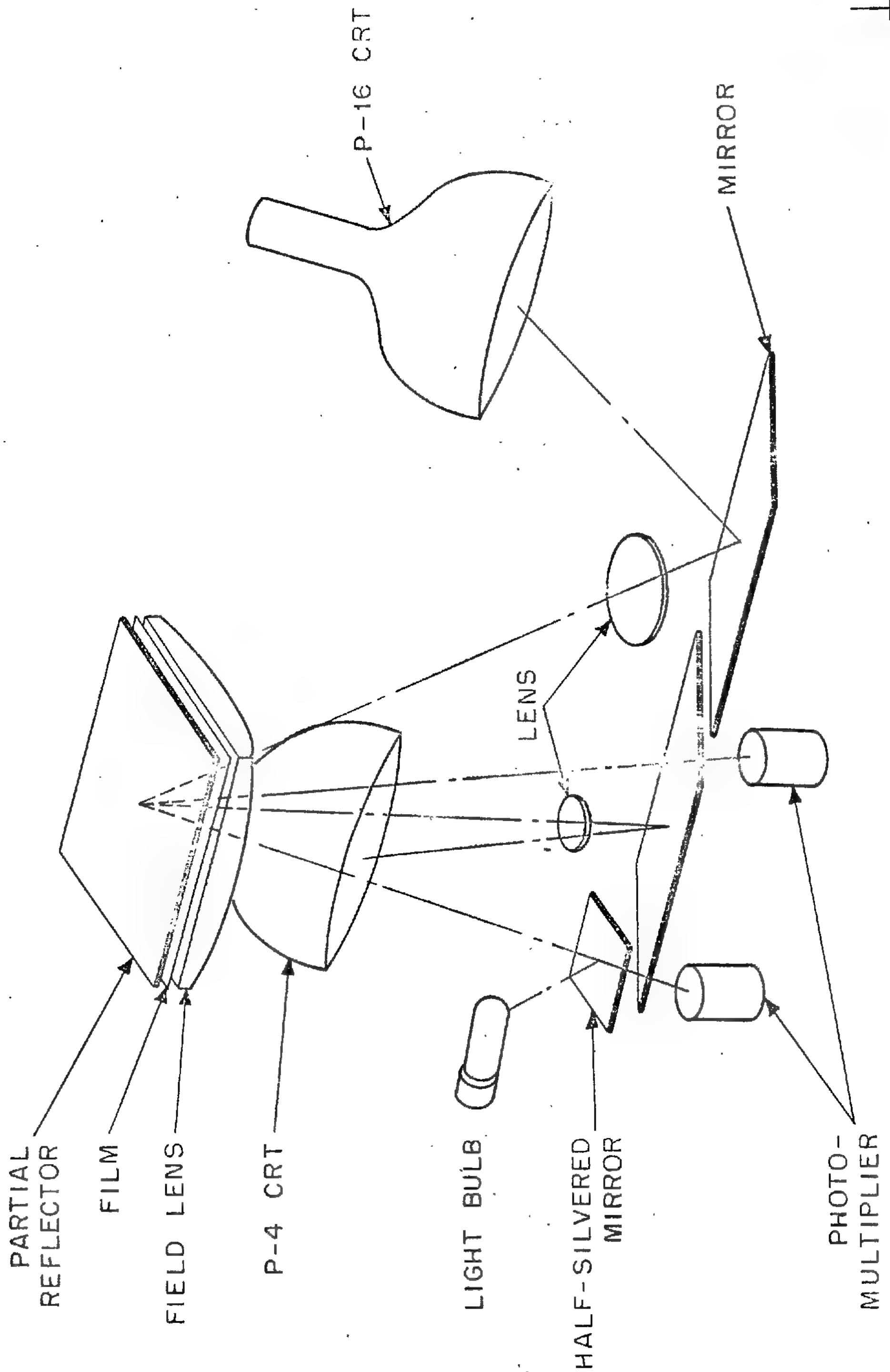

Figure 6. CRT Modulation With Phosphor Quenching

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light that can be handled by a conventional lens system. As mentioned, a P-28 phosphor can be quenched quite readily; however, this phosphor is primarily green. It is possible to adjust the cadmium-zinc ratio to obtain a whiter light and still retain the quenching feature.

This approach should only be pursued if the dynamic range of the CRT modulation is found to be inadequate.

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SECTION III - WORK STATEMENT AND PROJECT ORGANIZATION

1. DETAILED WORK STATEMENT (See Schedule - Page 34)

The Phase One program will consist of four tasks: (1) A Review of Applicable Approaches, (2) Implementation Studies, (3) Fabrication of a Breadboard Device, and (4) Laboratory Testing and Evaluation. This effort will be completed in six months from contract award.

The Phase Two program will consist of the fabrication and delivery of an operational prototype model of a Modulated-Light Film Viewing System. This program will be initiated only after demonstration of implementation feasibility and approval by the customer.

a. Phase One

Task 1 - A Review of Applicable Approaches

This task will consist of a detailed review of approaches that will modulate the intensity of a backlight according to the spatial frequency and transmissivity of the film. This will include an investigation and analysis of scanning techniques, phosphor quenching, photochromic and prototropic materials and various combinations thereof. Particular attention will be given to resolution and dynamic range, as well as ease of implementation. The output of this task

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will be the selected approach to be used for feasibility demonstration.

Task II - Implementation Studies

This task will consider the problems of implementation of the modulation technique selected in Task I. Critical implementation areas will be determined and predesign studies conducted in these areas. In addition, the design of the feasibility breadboard will be established. It is anticipated that only the critical areas, such as the detection and modulation system, will be breadboarded.

Task 3 - Fabrication of Breadboard Device

The critical areas of the Light-Modulated Film Viewing System will be breadboarded. This will include the detection and modulation system, auxiliary illumination system and viewing surface.

Task 4 - Laboratory Evaluation and Testing

This task will consist of a detailed evaluation of the breadboard device. This will include a qualitative evaluation using typical film images to be supplied by the customer. In addition, quantitative measurements will be made using a photometer. It is expected that the latter portion of the evaluation will be done in conjunction with

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a representative of the customer.

b. Phase Two

Phase Two of this program will consist of the design, fabrication and checkout of an operational prototype of the Light-Modulated Film Viewing System. This system will have a viewing area of 10x20 or 10x40 and will have auxiliary illumination outside the light modulated area which will be 9"x9". The brightness of the backlight will be at least 1000 foot-lamberts. The system will have provisions for reducing the light modulated area and positioning the center of the reduced area within the 9x9 inch area. The system will have capabilities for handling all film sizes up to and including 9 inch.

Included in this program is the generation of a final report which will include instructions for maintenance and operation.

2. PROJECT ORGANIZATION

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A project organization will be set up within the Avionics and Electronics Research and Development Division of the [redacted] engineering organization for the specific purpose of accomplishing the objectives of the proposed program. The principal investigator will be [redacted]

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[redacted]

The principal investigator will be responsible for the technical management of the program including planning, schedules, review and submittal of all technical reports. It is anticipated that all work proposed herein will be performed by [redacted] personnel in existing facilities, which are adequate for this program. However, should it become necessary or desirable to use the assistance of another supplier, [redacted] will follow normal procedures for the selection of subcontractors, with the approval of the customer.

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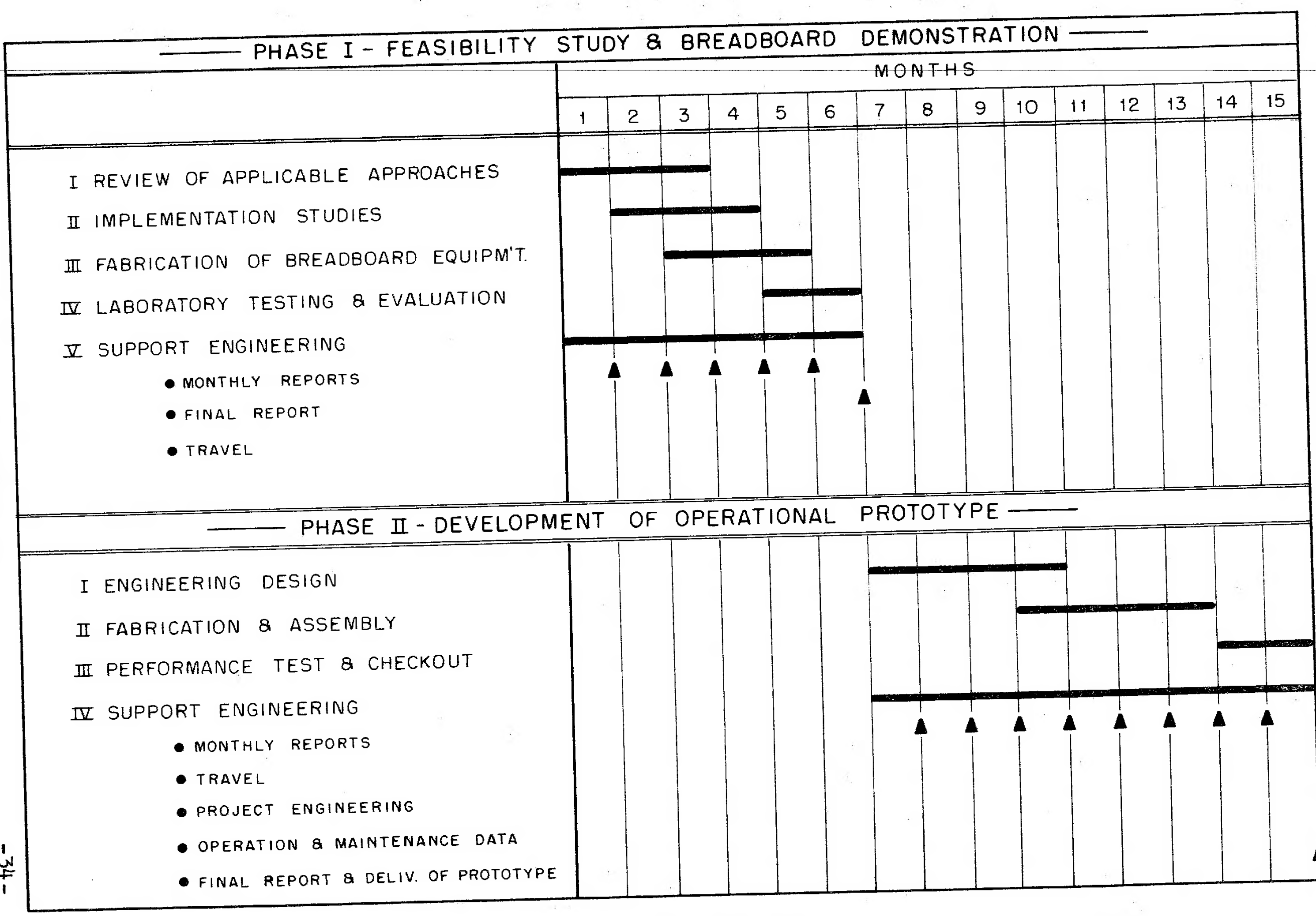

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Program Schedule

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